Marine energy exploitation in the mediterranean region: steps forward and challenges

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Marine Energy Exploitation in the Mediterranean Region: Steps Forward and Challenges

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This works aims to describe current perspectives for marine energy exploitation in the Mediterranean basin, highlighting challenges and opportunities as well as the factors that still limit its market deployment. Technologies for the conversion of Marine Energy (ME) into electricity are now ready for full-scale deployment in farms of devices, making the final step from demonstration to operability and commercial exploitation. Although marine energy is more abundant along the Atlantic and Nordic European coasts, significant resources are also available in the Mediterranean Sea, opening up new perspectives for sustainable energy production in sensitive coastal areas and for the economic development of Southern Europe. The implementation of ME converters in the Mediterranean is in fact liable to induce significant technological advancements leading to product innovation, due to the local low energy levels which impose more restrictive constraints on device efficiency and environmental compatibility. In addition, the milder climate allows the testing of concepts and prototypes in the natural environment at more affordable costs, lowering capital risks for new and innovative small and medium enterprises. Research institutions and industrial players in Mediterranean countries have already taken up the challenge, despite the numerous limiting factors that still need to be removed. In particular, the ME sector adds up to the many different traditional maritime activities and to the new ocean-related industries that are developing, potentially exacerbating the competition for the use of marine space in the Mediterranean region and threatening its environmental status. The ME sector needs therefore to design suitable instruments to involve all the relevant stakeholders in a participative public debate as to how to best manage the maritime space. As the prospective sea use patterns are rapidly changing, an adequate international legal and policy framework needs to be designed for the coherent management of sea space, and Marine Spatial Planning needs to be finally implemented by EU Member States also in the Mediterranean area. To this end, the creation of transnational clusters of stakeholders is expected be an effective catalyzer, especially as they can foster the exchange of knowledge and best practices both across European countries and between the North and the South shore of the Mediterranean basin.

Keywords: Mediterranean, marine energy, blue growth, tidal energy, wave energy, interreg-med

INTRODUCTION

During recent years, the EU has progressively intensified its coordinated efforts to finally achieve the Energy Union, by accelerating the implementation of actions supporting its core objectives i.e., security of supply, sustainability and competitiveness), while the necessity was still recognized to continue rapidly delivering a number of enabling measures, to ensure that the transition to a low carbon economy fully contributes to the modernisation of Europe's economy (Communication From The Commission To The European Parliament, 2017). A number of dedicated programmes and projects have therefore been funded in order to make progress toward the realization of five closely related and mutually reinforcing dimensions: energy security and diversification, a fully integrated internal energy market, energy efficiency, the decarbonization of the economy and the development of research, innovation and competitiveness.

Among the available renewable sources, marine energy is experiencing increasing interest and development (Jeffrey et al., 2013). Marine Energy comprises offshore wind energy plus energy that can be harnessed from the ocean (namely surface waves, tides/currents, and thermal and salinity gradients), the latter referred to as Ocean Energy (OE). The phrase *Blue Energy* (BE), which is also used in the following when appropriate, indicates both marine energy and the energy obtainable from marine biomasses.

The Marine Energy (ME) sector clearly stands at the intersection of all the converging paths of EU energy policy, as it promises substantial breakthroughs in low-carbon and clean energy technologies, reinforces the EU competitiveness on the global market, calls for transnational regulation and management (also in view of the Maritime Spatial Planning Directive - 2014/89/EU), reduces dependence on energy imports by leveraging indigenous resources, lowers emissions and drives the economic growth of coastal communities (TP Ocean, 2016). As a matter of fact, the Blue Growth Strategy proposed by the Commission in 2014 (COM(2014) 254) emphasized that harnessing the economic potential of Marine Energy in a sustainable manner represents a key policy area for the EU, which would enable the sustainability of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources. The ME sector is, in fact, expected to drive the creation of high-quality jobs and pave the way for a new wave of science-trained professionals, enhancing eco-efficient value creation all along the value and supply chain. In particular, remote islands and coastal regions would especially benefit from ME development, as it would provide a viable alternative to expensive and heavily polluting fossil fuelled plants, and contribute to their energy self-sufficiency (Rusu and Guedes Soares, 2012; Fadaeenejad et al., 2014; Franzitta et al., 2016; Franzitta and Curto, 2017). Moreover, small and medium sized port (SMP) management and the marine energy industry have mutually reinforcing interests, as SMPs could offer sustainable yet relevant marine services and satisfy their own needs of electricity by incorporating devices in port structures, at the same providing excellent sites for testing and monitoring new devices.

ME exploitation clearly opens new frontiers in the maritime sector, by creating synergies with long established traditional activities, yet opening the door to knowledge-driven innovation. It offers the opportunity to pool costs and boost several connected economic sectors.

The European Strategic Energy Technology (SET) PLAN recently prioritized Key Actions for the ocean energy sector, aiming at confirming the EU global leadership in the field, and filling the residual gap between research or prototype demonstration projects and their commercial deployment. Substantial reduction of costs is essential, as well as further demonstration of technology reliability and survivability in aggressive sea conditions. The SET Plan recommends to concentrate efforts on a limited number of promising technologies for energy conversion from tidal streams and waves, targeting the necessary reduction in the levelised cost of energy (LCoE) to improve their competitiveness in the electricity market (European Commission, 2017a).

Offshore wind farms probably represent the most advanced solution if the technological maturity of converters alone is considered, as they can rely on the expertise gained in several years of exploitation of their land-based analogs and on the stronger and less disturbed winds that are available offshore compared to on-land. On the other hand, devices for the production of wave and tidal generated electricity are in fact currently exiting the research and development stage and stably entering the operational, commercial phase, and the deployment of full-scale prototypes in real-sea environment is now underway (Magagna and Uihlein, 2015a,b; Magagna et al., 2016).

In this framework, the Mediterranean area in particular presents a variety of cross-boundary issues. Under current emission scenarios, the Mediterranean is and will be more and more affected by climate change in the course of the twenty first century, with severe impacts on the environment and human welfare (IPCC, 2014). The traditional economic activities that have been guaranteeing the livelihood of coastal communities for centuries are all at risk, in particular agriculture, fisheries and tourism. The adoption of sustainable and efficient forms of energy production clearly lies at the heart of the climate change mitigation issue, while the on-site development of renewables would at the same time address the growing local energy demand and secure the sustainable energy independence of coastal areas. Investments in the sector of renewable energy can no longer be delayed if the costs of non-action are to be counterbalanced (Plan Bleu, 2008). However, that of energy demand, efficiency and sustainability in the Mediterranean is a tale of two shores. As a matter of fact, the North countries have already taken a transition path by substantially introducing renewable sources in their energy mix and by effectively implementing measures to lower their energy demand. On the contrary, the South Mediterranean has experienced sustained economic and population growth over the past years (+6% and +5% respectively), with an energy demand growth of +6% since 2010 (MEDENER/OME, 2016), still insufficient measures to improve energy efficiency and renewable energy exploitation (United Nations, 2012; MEDENER, 2014), and little of no attention for marine renewables (El-Katiri, 2014; Bekkar Djelloul Saiah and

Boudghene Stambouli, 2017). Such an interest has been revived only recently, and marine energy proposed as a resource for coastal areas (Mahdy and Bahaj, 2018; Olaofe, 2018). Indeed the latter, together with small islands, deserve special consideration as they are subject to enhanced seasonal energy demand due to the tourism industry, both in the North and in the South Mediterranean (UNEP/MAP., 2000; Pirlone and Spadaro, 2017).

Developing and implementing marine energy technologies has not been so far a priority in the Mediterranean, as it was considered less cost-effective when compared to other renewables (e.g., solar or land-based wind energy). Offshore wind farms are not yet operational in the Mediterranean Sea despite the large resource availability (deCastro et al., 2018), due to both environmental and technological constraints and non-market barriers (EWEA, 2013), while OE converters are still at a pre-commercial stage (Uihlein and Magagna, 2016). Nevertheless, the share of marine energy in the total energy budget for the Mediterranean region is expected to constantly increase in the forthcoming years, in particular as regards offshore wind energy generation (EWEA, 2013; Piante and Ody, 2015), while the potential contribution of ocean energy is still often underestimated (see, for instance, Piante and Ody, 2015). On the contrary, recent technological advancements have made the targeted LCOE of OE converters more realistic (European Commission, 2017b), while the overall consideration of both explicit and implicit costs in the Mediterranean fragile environment (e.g., including the effects of landscape disruption and changes in land use) strongly recommends the adoption of less invasive devices for energy conversion such as these. Stepping up the role of ocean energy in the Mediterranean now appears more a necessity than a choice, as testified by the increasing interest of local authorities and administrative bodies (e.g., the Italian ANCIM, Associazione Nazionale Comuni Isole Minori-National Association of Municipalities located in Small Islands).

In the context of such renewed interest, the Mediterranean Sea has been proved to offer substantial opportunities for both significant energy production (Zodiatis et al., 2014; Monteforte et al., 2015; Besio et al., 2016) and technological development. The latter is mainly favored by the milder climatic conditions with respect to the North Sea And the Atlantic Ocean, which allow the affordable testing of devices and stimulate the design of particularly efficient technologies for energy harvesting. On the other hand, the accentuated vulnerability of the Mediterranean environment and sensitive species (e.g., Poseidonia meadows) prompts the development of innovative technologies that, while guaranteeing the energy independence of coastal areas, also preserve local exposed habitats and ecosystems. Under this respect, the design of a methodological framework for the environmental impact assessment (EIA) of OE converters has been recommended (Margheritini et al., 2012; Witt et al., 2012).

Building on their long-standing experience in maritime activities, R&D institutions and private enterprises in Mediterranean countries have been striving to gain and consolidate their position also in the marine energy sector. However, the still too low level of coordination and networking among the potential actors and the absence of a long-term stable funding programme on the part of national governments have prevented the sector from obtaining visibility and securing the essential sustained support from large enterprises, administrative authorities and local governing bodies.

In particular, OE technologies that have been specifically developed for the Mediterranean environment now need to complete their technological readiness level (TRL) path and enhance their visibility on the international stage (Sannino and Pisacane, 2017). In addition to the usually acknowledged barriers to industrial roll-out and final commercialization (technology development, finance, consenting and environmental issues, and the availability of grid infrastructure), the timeline for their further development also critically depends on the level of public support offered in the short- and medium-term by the EU, by national governments and by regional authorities (Negro et al., 2012). The provision of significant stable and predictable funding would prevent the loss of the accumulated knowledge now that it is close to repaying the initial investments made by national and international research programmes and private enterprises, and reinforce the position gained by Mediterranean players. Unfortunately, national investments are often insufficient to guarantee their participation in co-funded EU programmes and their access to co-funded financial instruments (e.g., OCEANERA-NET Cofund, http://www.oceaneranet.eu). The implementation of effective government policies, often solicited in EU official documents, would definitely sustain the improvement of technologies, bring down costs, and facilitate project financing, in a clear regulatory framework (Communication From The Commission To The European Parliament, 2014; Corsatea, 2014; Magagna and Uihlein, 2015a,b; Ocean Energy Forum, 2016; European Commission, 2017c).

As many reviews and reports are already available that deal with the status of marine energy development in Europe in general that contain information about the most popular devices developed in Northern and Atlantic Europe (Magagna and Uihlein, 2015a,b; Magagna et al., 2016 and references therein), this paper will only focus on the endogenous resources and efforts of Mediterranean countries, in terms of innovative devices, support technologies, environmental assessments and current policy instruments. The paper is organized as follows: Section Technologies for Marine Energy harvesting briefly reviews the most promising converters and the technologies involved in the supply chain, section Dedicated policies presents relevant policies implemented at the EU and at the regional and national level and Section Sustainability deals with sustainability issues, while key messages are summarized in the Conclusions.

TECHNOLOGIES FOR MARINE ENERGY HARVESTING

As already mentioned, offshore wind appears to be the closest-to-market ME technology, while the most promising ocean energy technologies are:

- Converters extracting kinetic energy from tidal currents;

- Converters exploiting the difference in potential energy arising from the rise and fall of sea levels between high tide and low tide (tidal range);
- Wave energy converters, extracting kinetic energy from wind-driven waves;
- Ocean Thermal Energy Converters, exploiting temperature differences between deep and surface ocean waters;
- Salinity gradient converters, harnessing the chemical potential of differences in salt concentration in ocean waters.

Although Northern and Atlantic European countries have made more progress on the road to marine energy exploitation, also Mediterranean countries can boast a high number of qualified developers from Universities, Spin-offs, SMEs and large Enterprises. For a survey of the Italian initiatives in the OE sector (see Sannino and Pisacane, 2017), while information about recent developments in Italy, Spain and France can be found in (OES, 2017) (the two latter mainly concentrating efforts outside the Mediterranean basin).

Efforts have been mainly concentrated on wave and tidal energy converters, which represent the most apt and promising options for the Mediterranean conditions, and for which different technical solutions were developed, either by adapting existing technology or by designing innovative devices. Several prototypes and pre-commercial devices have been designed and tested, some of which are now entering the commercial phase. The main advantage offered by such technologies is that, by being specifically projected for the Mediterranean environment, they had to specifically address the issue of efficiency, due to the relatively low wave energy levels in the basin. On the other hand, in order to export these technologies to the global market, it is necessary to prove their survivability in more severe sea conditions and the actual feasibility of their upscaling.

Parallel technological research and innovation activities are being conducted to enhance the efficiency in energy conversion and/or in storage and distribution, and transversally affect all the marine energy technologies.

Devices for the Conversion of Marine Energy

Wave Converters (WECs)

Several technologies for wave energy conversion have been developed, reaching different stages of technological maturity, and some full-scale prototypes have been already tested in real ocean conditions (Cagninei et al., 2015; Arena et al., 2016; Iuppa et al., 2016). The mechanical process of wave energy absorption and conversion requires a moving interface, which can either be a partly or totally submerged moving body whose kinetic energy is exploited by a Power Take Off (PTO), or a moving air/water interface subject to time-varying pressure as a function of wave incidence. The latter solution is known as Oscillating Water Column (OWC), and exploits the alternate compression and decompression induced by waves on the air trapped in the device, forcing air to flow through a turbine coupled to a generator. The main advantage of the OWC vs. other WECs is its simplicity, as the only moving part of the energy conversion mechanism is the rotor of a turbine, located above water level, rotating at a relatively high velocity and directly driving a conventional electrical generator. However, they only appear to be cost effective when incorporated in onshore conventional breakwaters, offering the advantage of a limited increase in costs in conjunction with ease of maintenance and coastal protection, while their use in large floating platforms has not been proven feasible (Falcão and Henriques, 2016). As a matter of fact, when any wave converter is located away from the coast, where waves are higher and potentially offer larger energy resource, both risks and expenses are liable to increase due to more severe sea conditions impacting both on the device and on the necessary submerged structures and electrical connections to the distribution grid (Rahm, 2010). The feasibility of offshore plants crucially depends on the availability of advanced mooring material and technologies, as well as of robotics, and informatics for the remote monitoring and efficient operational support (Borthwick, 2016).

The first full-scale OWC prototype in the Mediterranean is under construction in the port of Civitavecchia (Rome, Italy), as the Port Authority recently decided to upgrade its infrastructure and adopted the REWEC3 technology for the realization of 17 new caisson breakwaters. Each REWEC3 caisson is 33.94 m long and includes 6-8 independent absorbing chambers. The total length of REWEC3 caissons is 578 m. A first Wells turbine of 20 kW, without any optimization, has been installed, while the total installed power will be of 2.5 MW (Arena et al., 2016; Sannino and Pisacane, 2017).

Wave converters developed by the Israel-based company Eco Wave Power have been cemented to the sea wall surrounding Jaffa Port, where a 10 KW research and development power station has been installed (http://www.ecowavepower.com/jaffa-port/). Most of the technical equipment operates on land, thus improving reliability, reducing stress on equipment and providing easy access for maintenance and repair. In 2016, Eco Wave Power also installed the first commercial wave energy array in Europe selling electricity to the electrical grid through a PPA (Power Purchase Agreement) with the Government of Gibraltar and the Gibraltar Electricity Authority. Upon completion of the whole 5 MW, this site will provide Gibraltar 15% of its overall consumption of electricity.

In August 2015, the first full-scale prototype of the Inertial Sea Wave Energy Converter (ISWEC, TRL 7), a point-absorber suitable for mild climate seas such as the Mediterranean, with a nominal power of 100 kW, was moored 800 m from the coast of Pantelleria, Italy (Cagninei et al., 2015), while the H24 wave energy converter developed by 40 South Energy was installed off Marina di Pisa, in Tuscany (Italy).

However, transparency and accountability issue arise as to the actual performance of devices in real sea conditions, and as to their operational behavior. The lack of public data often impairs the fair comparison of the proposed technologies, while an objective evaluation of technology progress through the adoption of common metrics is indeed necessary to illustrate the impact of funding and to ensure appropriate allocation of future funding to the most promising technologies (European Commission, 2017c; OES, 2017).

Tidal Current Converters

Tidal energy technologies extract kinetic energy from either sea level fluctuations (through tidal barrages, usually effective in resonant estuaries) or from tide-driven currents (tidal energy converters - TECs). A PTO then converts mechanical motion to electricity. The local low tidal excursion and the marked dependence of the energy of tidal currents on local conditions and topography, suggest that only TECs can be considered as promising technologies for specific location in the Mediterranean, namely the straits.

There is a wide variety of TECs available (Magagna and Uihlein, 2015a,b and Magagna et al., 2016; Sleiti, 2017), whose suitability clearly depends on the application under study. Again, technologies specifically designed for the Mediterranean environmental conditions are being developed (Sannino and Pisacane, 2017), while a prototype of the Kobold vertical axis turbine (6 m diameter) has been installed in the Strait of Messina (Coiro et al., 2013). However, due to the limitation and constraints for the optimal siting of TECs in the Mediterranean, no extensive studies as to their potential performance and exploitation have been conducted so far.

Offshore Wind Energy and Multipurpose Platforms

Offshore wind-turbine technology has essentially followed that of its onshore analog. Turbines usually consist of three blades rotating around a hub, with rotor diameter well above 100 m and hub height around 100 m, reaching a rotational speed of 10 rpm and nominal power production just below 10 MW, but rapidly increasing as development continues. Their technology is in fact rapidly evolving, and it appears feasible to further upscale individual wind turbines, although problems might still arise from noise and blade erosion (Borthwick, 2016). Their use in arrays (wind farms) is now widely implemented, and at the end of 2017, the total worldwide offshore wind power capacity was nearly 19,000 MW (GWEC, 2017).

However, the installation of offshore wind farms in the Mediterranean has been so far hindered by the characteristic depths of the basin, which do not allow fixed foundations for the turbines at a distance from shore that is at the same time compatible with landscape preservation and cost effectiveness. After substantial delay, mainly due to public opposition, which led to longsome appeals to the Administrative Court, the first near-shore plant is currently under construction in Taranto, Italy, with total capacity 30 MW (https://www.4coffshore.com/windfarms/parco-eolico-nella-rada-esterna-del-porto-di-taranto-italy-it31.html).

The exploitation of wind power in the Mediterranean is in fact still in want of appropriate and innovative solutions for offshore foundations and floating support structures specifically designed for deep waters, so as to allow distancing the installations from the shore and preserving valuable landscapes (Borthwick, 2016; Soukissian et al., 2017; deCastro et al., 2018). An analysis conducted in 2013 by the European Wind Energy Association concluded that deep offshore designs were necessary to unlock the promising offshore market potential in Mediterranean, developing technologies that could be globally exported, initially to Japan and the US. It also foresaw that the first deep offshore wind farms could be installed and grid connected by 2017, provided the challenges then existing were overcome (EWEA, 2013). As a matter of fact, the first pilot floating farm is now going to be installed 15 km off the coast of Gruissan, in the Gulf of Lion, France, for a total capacity of 24.8 MW (http://www.eolmed.fr/en/the-pilot-farm/).

The opportunity of integrating offshore wind technologies and WECs on multipurpose platforms, possibly also hosting different maritime activities such as aquaculture or maritime transport, is currently being explored, as it allows cost sharing and the more sustainable planning and management of the electric grid and of auxiliary infrastructures (Pérez-Collazo et al., 2015; Astariz and Iglesias, 2016; Craig, 2018; Di Tullio et al., 2018). In particular, the inclusion of co-located WECs into wind farms would further accelerate the development of wave energy technologies, and prompt the adoption of a common regulatory framework and the development of simplified yet rigorous licensing procedures, in compliance with the Maritime Spatial Planning (MSP) Directive and with Integrated Coastal Zone Management (ICZM) principles (Pérez-Collazo et al., 2015; Astariz and Iglesias, 2016). The integration of multiple different sea energy converters would also guarantee a smoother power output and minimum energy production at a constant rate independently of meteorological conditions, therefore ensuring the survival of security systems and power transmission systems, and increasing the platform service factor (Stoutenburg et al., 2010). The operational life of the offshore platforms would therefore be lengthened, positively responding to the financial and insurance concerns of investors and increasing the interest of potential stakeholders. Studies concerning trade-offs and synergies with other economic sectors responsive to marine resources exploitation, such as aquaculture, maritime transports, beach tourism, naturalistic tourism, or installations for biotechnologies, are also underway, which are attempting to assess the economic potential and risks of co-using sea areas, as well as the mutual effects on the sustainability of the concomitant uses (Buck and Krause, 2012; Leira, 2017).

Support Technologies

The positive international outlook for ocean energy deployment has also induced researchers involved in subsidiary fields and potentially connected industrial players to approach the marine renewable sector. Many industrial sectors of Mediterranean countries in fact actively contribute to designing the building blocks of innovative ocean energy converters, either by developing ad hoc technologies or by optimizing existing ones, while research institutions, environmental agencies and operators of the green economy constantly strive to enlarge the existing database of environmental and product design constraints.

Environmental Modeling: Resource Availability, Environmental Impact Assessment, Optimal Design of Installations and Operative Parameter Tuning

For the exploitation of marine energy it is essential to determine where sufficient resource exists, so as to guarantee adequate return on investment and increase the confidence of investors by minimizing risks (Uihlein and Magagna, 2016).

Forecast systems delivering reliable and updated maps of relevant parameters, such as significant wave height, wave energy period and mean wave direction, need then to be considered as a component of the engineering of devices, as they allow optimal plant siting and calibration, predictive maintenance, and a better understanding of site characteristics and vulnerabilities.

Despite marine energy being characterized by higher predictability with respect to other renewables (tidal current energy is periodic, while wind is less subject to disturbances offshore than onshore), as the size and complexity of the installations increases, the tools used to project or measure the resource, and to assess the environmental impacts of the plants, become more and more critical and need to integrate a variety of complex modeling and monitoring techniques, also in view of the accentuated variability in the basin, which cannot rely on the comparatively coarse resolution, non-specific, projections available through international websites (Uihlein and Magagna, 2016). Several international programmes and projects have been dedicated to the improvement of projections and assessments for the Mediterranean area, often already in view of future exploitation opportunities (e.g., the on-going H2020 Project MUSES - https://muses-project.eu/ - and the FP7 Project COCONET - https://www.coconet-fp7.eu/). In particular, the MED-Cordex Initiative (https://www.medcordex.eu/) provides projections from regional atmospheric, land surface, river and oceanic climate models as well as from coupled regional climate system models, aiming to increase the reliability of past and future regional climate information for the Mediterranean region (Ruti, 2016).

In addition to these time-limited or climate-oriented coordinated efforts and to the EU-wide support provided by the Copernicus services (http://copernicus.eu/main/marine-monitoring), research centers in many Mediterranean countries routinely provide environmental forecast for general or specific use based on national initiatives (e.g., http://openskiron.org/en/).

In Italy, for instance, specific support to ocean energy related activities is offered at ENEA, by performing ocean wave modeling activities aimed at both quantify ocean energy availability in the Mediterranean Sea (**Figure 1**) and at providing the necessary information for the optimization of the operational set-up of wave energy converters. A wave forecast system was developed and validated by ENEA in collaboration with Enel Green power, and has been operatively running since June 2013 (https://giotto.casaccia.enea.it/waves/). Forecasts cover the entire Mediterranean basin while nested higher resolution projections are provided for 10 sub-basins along the Italian coasts. A sample projection for the western coast of Sardinia is shown in **Figure 2**. When coupled to real-time measurements, the forecasting system can further support the operation of wave energy generation devices, predict actual electric power generation and give the alert in case of severe sea conditions.

ENEA is also running climatological experiments with a high-resolution tide resolving ocean model (MED-MITgcm) capable of assessing the available tidal power in selected locations in the Mediterranean basin (**Figure 3**).

Similar activities, for specific sites or periods, are also carried out at several academic and research centers in the context of specific national projects (Sannino and Pisacane, 2017).

The private sector as well has developed environmental services in the support of sea-based operations. Large consulting companies (for a review of those operating in the Mediterranean see Sannino and Pisacane, 2017) are capable of performing meteo-ocean modeling and to offer support for the optimization of design parameters of engineering projects in offshore

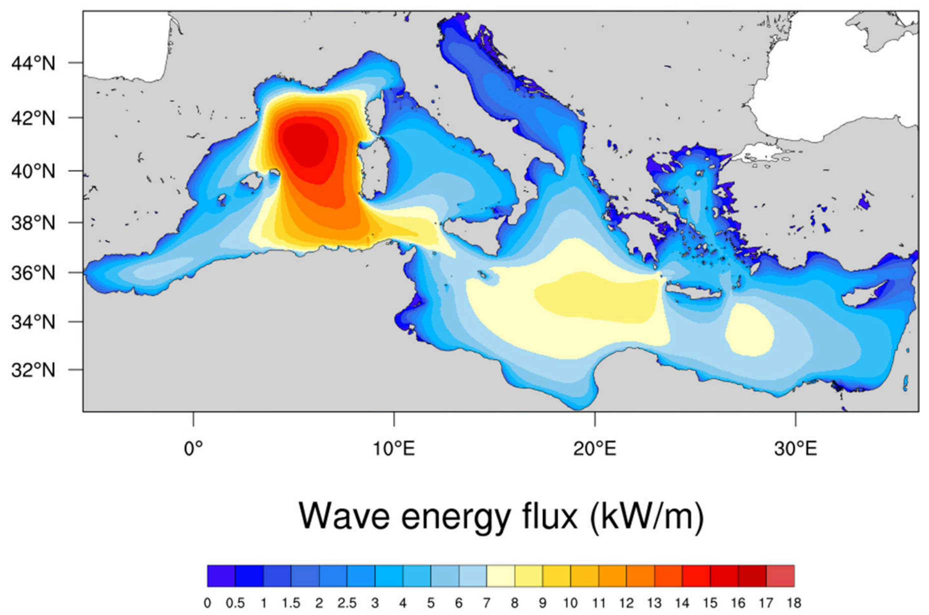

FIGURE 1 | Mean climatological wave energy flux in the Mediterranean for years 2001–2010.

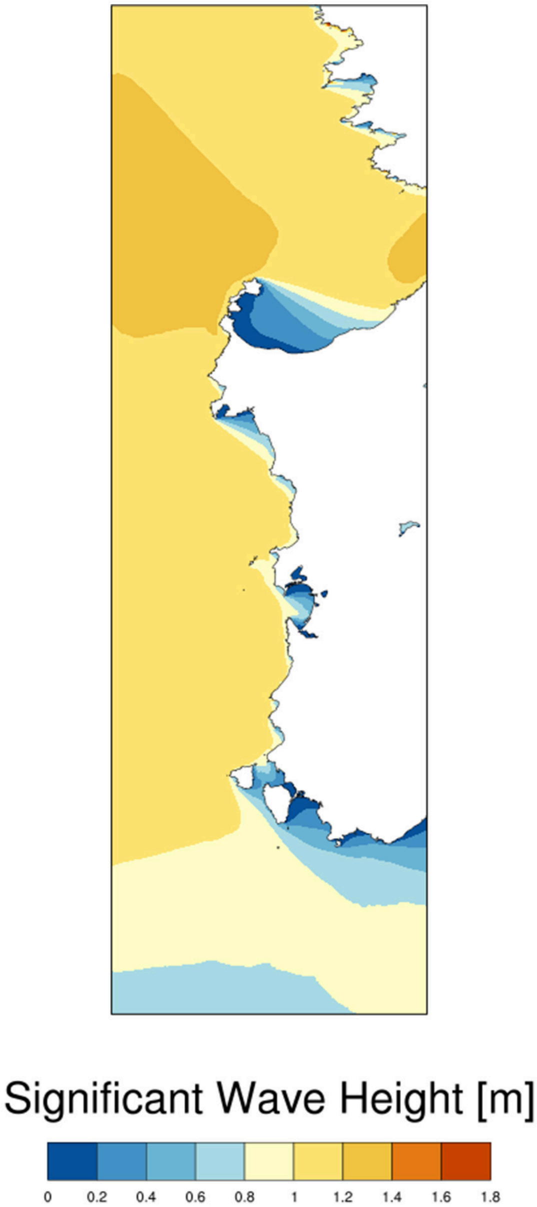

FIGURE 2 | Sample forecast of Significant Wave Height along the West coast of Sardinia.

areas (platforms), marine, waterfront (harbors) and coastal (beach protection) environments, and the minimization of their environmental impacts. Offshore geotechnics services are carried out for offshore platforms, subsea structures, pipelines, floating structures applications, including non-linear dynamic modeling capacity. Characterization of the typical environmental conditions and processes at the project site is therefore feasible, including longshore/cross-shore sediment transport and contaminant dispersion. Innovative monitoring systems for the design, installation and management are also available on the market.

In their turn, large national and international utility companies (e.g. ENEL, https://www.enelgreenpower.com/) also carry out strategic activities in the Mediterranean to support the development of promising devices and to predict and classify the potential environmental risks of marine energy plants from concept to decommissioning. Sites characterized by lowest sensitivity to project characteristics can then be selected and the associated socio-economic impacts evaluated.

Device Optimization

Besides optimal siting, further development of devices for marine energy conversion also requires the careful assessment of the expected performances in realistic operative conditions in the Mediterranean environment, where most of the existing wave power technologies are oversized. *Ad hoc* numerical models for the performance assessment of the most promising concepts are consistently implemented by technology developers, which virtually mimic the mechanical and hydro-dynamical and the electrical aspects of devices, also accounting for the control system, for the characteristics of their industrial components and for the constraints of grid connections (Bozzi et al., 2013; Folley, 2016). Simulations are carried out in a variety of sea conditions and multiple device arrangements, and finally provide optimal configuration and scaling, geometrical layout and layout orientation, together with the estimate of maintenance requirements and yearly average productivity (Sannino and Pisacane, 2017 and references therein, Lopez-Ruiz et al., 2018). Costly non-linear models are systematically upgraded to refine the system configuration around its best overall layout, and to assess the performance and productivity of wave farms as a function of location, mutual hydrodynamic interaction and electric connection, also estimating maintenance requirements and optimal operating conditions. These methodologies also analyse system response to severe sea states. Results are validated against available experimental data, providing however the added value of statistically significant uncertainty analysis based on large size data samples, and representing a key step toward the optimization of energy production by sea-based farms (Lopez-Ruiz et al., 2018).

Infrastructure Design and Development of Mechanical and Electrical Elements

The development of the ocean energy sector also needs innovative infrastructures and components that are capable of enduring the severe marine environmental stresses, making facilities less prone to faults and more cost-efficient, and guaranteeing their constant operability. Connected sectors such as marine construction, shipbuilding and electric power system design and operation would then envisage invaluable opportunities for growth, as they can re-adapt technological solutions developed in different contexts and partly re-orient their business and capitalize their experience (Ellabban et al., 2014; Magagna and Uihlein, 2015a,b; Borthwick, 2016). Both large enterprises and SMEs would in fact acquire new skills and capabilities by cooperating with cutting-edge research, confirming and enhancing their capacity of offering innovative, high-value solutions. On the other hand,

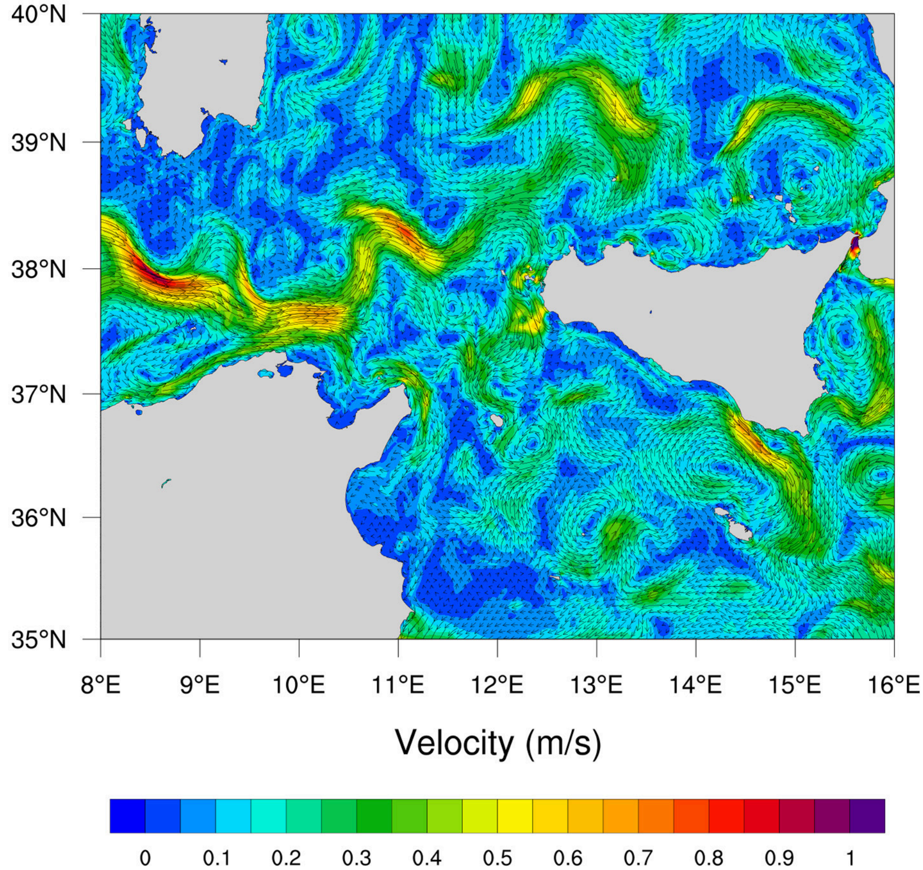

FIGURE 3 | Forecast of currents in the Sicily Channel and at the Strait of Messina.

academic research would largely benefit from the ability of established private firms to stay in a competitive market, and consolidate partnerships for the industrial roll-out of their concepts (Appleyard, 2017; European Commission, 2017c).

To give an outline of the variety of potentially connected sectors, either in the supply chain or in research and development, it is here worth considering:

- The Oil & Gas sector and the Shipyard & Shipbuilding industry, specialized in the construction of drilling platforms, floating platforms and offshore supply and cable laying vessels, and capable of delivering the economic assessment of the different phases in the lifetime of a floating structure, from construction to deployment;
- The electronics industry, offering innovative energy storage solutions and batteries for marine offshore applications, e.g. those based on the thermal and fluid integration of Proton Exchange Membrane (PEM) fuel cells and Metal Hydride hydrogen storage (prototype 1, completed), and on the electric and fluid integration of Electrolyser and RES[1] plus Metal Hydride storage for hydrogen production and storage (small scale prototype 2 – under development) (Lamberti et al., 2015);
- Companies providing cost effective solutions for onshore construction as well as hands-on experience in all areas of offshore geotechnics. Typical projects include offshore platforms, subsea structures, pipelines, floating structures, whose feasibility study is accompanied by quantitative risk assessments covering the full range of marine installation, and including the hydrodynamic and sea-keeping analysis of floating units, their mooring analysis, ship handling/maneuvering simulations, and the analysis of mechanical components (e.g., static and dynamic stress analysis, structural thermal coupling, vibration and fatigue analysis);
- Companies providing innovative and durable materials for submerged structures (e.g., new coatings and alloys);
- Manifacturing companies offering bearings, ballscrews and Electro-Mechanical Actuators (EMAs) and PTOs for the aerospace, industrial and energy sectors;
- Companies specialized in the design and production of Electro Submersible Pumps and turbines, whose performance under variable flow conditions is crucial in the low-energy wave conditions typical of the Mediterranean Sea;

[1] Renewable Energy Source

- Companies developing unmanned underwater robotics for the monitoring and surveillance of the infrastructures at sea;
- Companies offering integrated cable-less communication solutions for the Internet Of Underwater Things (IOUT), which open new possibilities for the installation and monitoring of infrastructures (FP7 Project SUNRISE).

Many of these enterprises have further consolidated their technical competences and contributed to the technological development of the ME sector by participating, in collaboration with potential customers and leading R&D institutions, to several regional, national and international research projects (Sannino and Pisacane, 2017).

Experimental Infrastructures

During the development of ocean energy converters from their first conceptual modeling to their deployment, scale prototyping and testing is crucial to correctly re-direct the design process. Small and medium scale prototypes are tested in wave flumes and wave tanks, where specific sea states can be artificially created, and power production and device survival assessed. For the correct downscaling of the system, the wave tank/flume features need to be taken into account, so as to construct the prototype according to the characteristics of the facility that is going to be used.

While universities usually offer facilities of limited size for limited applications, many specialized centers offer research infrastructures that include world-class towing tanks and flume tanks, simulating complex testing environments for wave, tidal, offshore wind energy systems. The MARINERG-i Project has recently been launched with the aim to create an integrated European Research Infrastructure, designed to facilitate the future growth and development of the Offshore Renewable Energy sector, in the framework of the European Strategy Forum on Research Infrastructures (ESFRI).

In addition to traditional infrastructures offering testing opportunities in laboratory conditions, the Natural Ocean Engineering Laboratory (NOEL) of the University of Reggio Calabria (UNIRC) provides a unique testing infrastructure in the marine environment, where field tests can take advantage of the dedicated sensors and data acquisition center, and be carried out with the support and assistance of specialized personnel (www.noel.unirc.it).

DEDICATED POLICIES

The EU SET Plan

The Strategic Energy Technology Plan (SET-PLAN) is part of a new European energy Research & Innovation (R&I) approach designed to accelerate the transformation of the EU's energy system and to bring promising new zero-emissions energy technologies to market. The SET-Plan intends to accelerate the development and installation of low-carbon technology. It attempts to enhance new technology and bring down prices, by coordinating Member States research efforts. It also aims to enhance project funding. The SET-Plan includes the SET-Plan Steering Group, the European Technology and Innovation Platforms, the European Energy Research Alliance, along with the SET-Plan Information System (SETIS). Within the SET-Plan organization, dedicated Working Groups (WGs) were created in 2017 for both ocean energy and offshore wind, which recently issued specific Implementation Plans, delineating priority actions to foster future developments (SET Plan, 2018a,b). Due to the different stages of development of ocean energy and offshore wind technologies, recommended actions clearly differ as to targeted objectives, relevant policies and funding sources foreseen, especially as regards the relative weight of public and private commitment. In particular, the offshore wind industry target reduction in the levelised cost of energy (LCoE) declared in the NER300[2] programme to less than 10 ct€/kWh by 2020 and to less than 7ct€/kWh by 2030 was reformulated by the WG, which indicated the even more ambitious objective of zero subsidy cost level, as a result of improved the performances along the entire value chain (SET Plan, 2018b). Less constraining targets are set for offshore wind farms in deep waters (>50 m), whose more costly substructures need to be considered as integral parts of the whole system, with expected LCoEs of less than 12 ct€/kWh by 2025 and less than 9 ct€/kWh by 2030 (SET Plan, 2018b).

On the other hand, the implementation plan delivered by the SET-Plan Working Group "Ocean Energy" (SET Plan, 2018a) aims to speed up the development of wave and tidal energy in Europe. The WG is composed of 10 EU Member States: UK, Italy, Spain, France, Belgium, Portugal, Germany, Ireland, Cyprus, Sweden. Stakeholders also joined the WG, represented by the relevant Government Agencies, Regional representatives, industry sectors representatives, research associations and the education sector.

The agreed common targets for the ocean energy sector are:

- Bring ocean energy to commercial deployment,
- Drive down the levelised cost of energy,
- Maintain and grow Europe's leading position in ocean energy and
- Strengthen the European industrial technology base, thereby creating economic growth and jobs in Europe and allowing Europe to compete on a global stage.

The WG also agreed on setting quantitative targets for the LCoE for tidal stream and wave energy:

The LCoE for tidal stream energy should be reduced to at least 15 ct€/kWh in 2025 and 10 ct€/kWh in 2030. Wave energy technology should follow the same pathway through convergence in technology development and reach at least the same cost targets maximum 5 years later than tidal energy: 20 ct€/kWh in 2025, 15 ct€/kWh in 2030 and 10 ct€/kWh in 2035.

Substantial reductions in LCoE will need to be obtained through a combination of development and deployment to ramp up 'learning by doing' and learning by innovation. Substantial improvements in technology performance and operational efficiency combined with mass production will deliver the necessary cost reduction and performance improvements of both tidal and wave technology. Overall the WG recognized that the combination of both step changes in innovation and considerable

[2]NER300 Programme: https://ec.europa.eu/clima/policies/lowcarbon/ner300_en

volumes of ocean energy devices need to be installed to achieve these aims.

National Policies and Lessons Learnt

European countries exhibit different degrees of participation in knowledge creation, diffusion and demonstration in marine energy technology, face different barriers to innovation activities and adopt different solutions for the removal of the factors hampering marine energy deployment (OES, 2017; SET Plan, 2018a). According to (SET Plan, 2018a), only France, Spain, Italy and Cyprus have prioritized action in the OE sector and allocated public funding, while only Italy and France have implemented government incentives in the form of feed-in tariffs (OES, 2017). In the offshore wind sector, where higher Technology Readiness Levels have been reached, national research and innovation programmes are usually limited to technologies up to TRL 7, while financial support provided by Member States to higher TRL technologies need to comply with the EU's State aid rules (SET Plan, 2018b).

In general, considering the whole European landscape, the UK, Ireland and the Nordic countries were early movers in the ME industry, and initiated an intense process of knowledge creation, whereas other EU countries are lagging behind, with limited investments that are mainly expected to be overcome by intensification of knowledge diffusion through EU funded projects and programmes (Corsatea, 2014). Among the latter, Italy has been trying to fill the gap and coordinate a national effort to gain visibility for its well-established activities in the sector (Sannino and Pisacane, 2017).

Even in the most advanced countries, however, policymakers were faced with the necessity to refine the policies in support to numerous and diverse product innovations, in order to get technologies closer to the market (Magagna and Uihlein, 2015b. In order to reduce the high cost of marine energy technology, "nursery markets" were accordingly created to provide opportunities for the infant industry to develop (e.g., publicly supported centers providing the infrastructure needed for the successful demonstration of marine devices). The UK is certainly a leader in this respect, while France and Sweden have started implementing public funded projects, and Germany is pursuing the involvement of multi-technology private companies (Corsatea, 2014).

In all countries, public support has been recognized as a crucial factor for early-stage research on marine energy technology, as it stimulates private investment, although national targets are apparently insufficient to create a long time horizon for private investors, due to the weak stringency and stability of national policies. As marine energy technology still faces significant cost constraints, stable mobilization/allocation of public resources is anyway needed for its further development. The birth of a policy community involving technology developers and marine industry, also involving intermediate levels of decision-making, is now necessary to foster the necessary positive environment for the development of ME innovation activities, enhancing synergies among participants (Borthwick, 2016; European Commission, 2017c). Tighter teamwork of all the relevant actors and more constraining targets would in fact foster market acceptance of the technology and be an effective innovation catalyzer and disclose existing potentialities (Corsatea, 2014).

Mediterranean countries are now entering the ME sector and transposing the EU directives in the matters of both energy policy and marine spatial planning. National legislations are therefore being designed, as well as adequate policy instruments. In the light of past experiences, the importance of networking and of the prospective role of large-size clusters of stakeholders has been acknowledged, resulting in specific initiatives (e.g., the Italian Technological Cluster for Blue Growth) and in public support to EU funded projects for the regional exploitation of ME technologies (Sannino and Pisacane, 2017). Nevertheless, authorization procedures must still comply with the complex legislation in force as to the protection of the environment, of the landscape, and of cultural heritage, and obtaining consent for the installation can be very complex, as it is necessary to ensure the involvement and coordination of all the authorities and tive bodies that represent and protect the different and diverse public interests involved (deCastro et al., 2018). Although streamlining authorization procedures has been timely recommended (SOWFIA, 2013), as well as the adoption of rigorous metrics to evaluate and monitor technological progress and environmental compatibility (European Commission, 2017c; OES, 2017), there is still a need to o accommodate some very different legal obligations arising not only from domestic law and EU law but also from international law, and EU Member States have to seek new forms of cooperation according to their needs and must be forced to effectively transpose the EU Directive on Maritime Spatial Planning into their national legislation and to establish transnational regional structures to face cross-border issues (Martinez Perez, 2017; Salvador et al., 2018).

Dedicated Regional Development Projects

The Interreg MED Programme, which is part of the European Territorial Cooperation (ETC) objective of the EU Regional Policy, was initiated with the ambition of contributing to the long-term development of the Mediterranean area and of strengthening transnational cooperation among 57 regions in 10 different EU member states and 3 candidate countries (MED Programme, 2015). In 2016, the EU Interreg-MED Programme launched the horizontal project InnoBlueGrowth - "Horizontal Communication & Capitalization project for Innovation in Blue Growth at Mediterranean level" (https://blue-growth.interreg-med.eu/), with the aim to implement concrete actions for the creation of cohesive stakeholders communities in strategic investment areas. Among the modular projects of InnoBlueGrowth, PELAGOS and MAESTRALE are specifically dedicated to marine energy. In particular, the PELAGOS Project (https://pelagos.interreg-med.eu) aims to define a management and coordination system among the participating countries (Greece, Italy, Portugal, Spain, Cyprus, France, Croatia), connecting the different components of the Quadruple Helix (i.e., the public sector, the business community, the higher education institutions and civil society) that represents the linkages and the potential conflicts between knowledge production and knowledge use in the field of marine energy. Its scope is to facilitate the deployment of targeted technological solutions and products that are tailored to the characteristics of the Mediterranean environment. It addresses both the request for adequate information and support expressed by the several direct stakeholders in the ME value chain, and the demand for economic, environmental and societal sustainability coming from private and public bodies and citizens. In the framework established by the EU directives in the matters of Regional Policy, Maritime Spatial Planning and Blue Growth, PELAGOS will establish a permanent Mediterranean Cluster of stakeholders to sustain macro-regional strategies and connect key actors of the Marine Energy sector (e.g., technology and service providers, large enterprises, power distributors, financial operators, policy makers, Non-Governmental Organizations (NGOs) and citizens), thus enhancing trans- national cooperation and the internationalization of efforts in the development of new marine based technologies that are both safe and economically feasible. It will support technology transfer and knowledge sharing, and stimulate the development of high-tech and sustainable infrastructures, so as to generate economic growth, to enhance the security of energy supply, to foster competitiveness, and to increase the demand of high-quality professionals in new sea careers. PELAGOS will implement Pilot Actions at both regional, national and transnational level, that will illustrate and provide services, tools and methods tailored to the needs of Small and Medium Enterprises (SMEs) and help highlight the actual obstacles and limitations to the development of the ME sector, at the same time identifying joint opportunities in key market sectors such as tourism & leisure, aquaculture and shipbuilding.

The role of trans-national clusters in creating a favorable environment for collaboration, and in enhancing technological development and economic growth through the sharing of facilities and tools among stakeholders, is a consolidated pillar of EU policy (European Commission, 2008, 2017c; ECO, 2016). In 2016, EU Directorate General Growth launched the European Cluster Collaboration Platform (ECCP), an action of the Cluster Internationalization Programme for SMEs funded under Europe's programme for small and medium-sized enterprises (COSME). The ECCP provides networking and information support for clusters and their members, aiming to improve their performance and increase their competitiveness through trans-national and international cooperation, and to build cluster bridges between Europe, its neighboring countries and the world (https://www.clustercollaboration.eu/).

On the other hand, the MAESTRALE Project (https://maestrale.interreg-med.eu) intends to lay out the basis for a Maritime Energy Deployment Strategy in the Mediterranean, concerted across partners from Italy, Spain, Croatia, Greece, Cyprus, Portugal, Slovenia, and Malta. Starting by making a survey of innovative existing technologies, hindrances and potentials in participating countries, it aims to widen knowledge sharing among scientists, policy makers, entrepreneurs and citizens and to prompt concrete actions and investments. Project partners will cooperate to detect maritime renewable energy potentials in participating countries as a function of their geographical, legal, technological, economic and social contexts. Environmental sustainability, technological innovation and public acceptance are specifically addressed, as well as possible adverse impacts on marine ecosystems. The main output of MAESTRALE will be the creation of Blue Energy Labs (BEL) in each participating region. BELs will include local enterprises, public authorities, knowledge institutions and citizens and will outlive the project to support future blue energy policies and plan concrete strategies for blue growth. Pilot actions are being implemented to raise awareness among local stakeholders, to increase social acceptance and to reduce the inherent uncertainties in impact assessments, thus augmenting the feasibility and effectiveness of interventions.

National support to such initiatives, as well as the inception of similar efforts at the national/regional level, and the complementary implementation of adequate financial support instruments, would definitely contribute to further expanding the ME sector, and to the implementation of solutions tailored for the different national contexts (European Commission, 2008). In particular, transfer of scientific information and exportation of best practices to countries of the South Mediterranean can be achieved through the joint efforts of MEDENER (the association of national agencies for energy efficiency and renewable energy), OME (the Observatory for Mediterranean Energy) and ADEME (Agence de Maitrise de l'Environnement). Such organizations already cooperate in sustaining the Mediterranean countries along their energy transition path, and in helping them to fulfill their ambitious national and regional objectives. The implementation of a regional platform to enhance knowledge exchange on energy efficiency and renewable energies would effectively reinforce Euro-Mediterranean cooperation in the field (MEDENER/OME, 2016), and complement the industrial cooperation effort undertaken through the ECCP.

SUSTAINABILITY

The sustainability of marine energy in general is constrained by economic, environmental, and societal issues (Copping et al., 2014; Bonar et al., 2015; Borthwick, 2016; Copping, 2018). As it is still far from being fully deployed, its impacts are likewise largely to be assessed, as well as the potential adverse effects. Mitigation measures are also still to be designed. While economic constraints are primarily due to the relative high LCOE of marine electricity (induced by higher capital and recurrent costs), to the stability of government subsidies, and to market volatility, reliable information on environmental and societal issues is largely missing, as well as the indirect economic impacts implied (Kerr et al., 2014). As a consequence, public responses to proposed renewable energy developments critically depend on the specific technology and location, and are influenced by a wide range of factors. Regulatory and consenting procedures, for instance, have not been clearly defined yet and still represent a significant barrier to the upscaling of tested infrastructures (European Commission, 2017c). This is also due to the existing uncertainties about their cumulative effects, which are still too large to convince managers and policy makers to ease their administrative scrutiny (Bonar et al., 2015; Borthwick, 2016; Willsteed et al., 2018). As a matter of fact, the development of

Marine Energy is part of an ongoing large-scale strategy for the exploitation of marine resources, namely the Blue Growth, that also includes a variety of possibly conflicting economic activities such as commercial fishing, shipping, aquaculture, dredging, spoil-dumping and oil and gas exploitation. The question of how to regulate the complex interactions of all the involved economic sectors, at the same time preserving (or, when appropriate, conserving) the environment has just been posed, and the "data-rich, information-poor" (DRIP) paradox regarding the assessment of potential modifications of the benthos is yet to be escaped, in particular as to crucial marine ecosystem services (Wright, 2015; Wilding et al., 2017).

Environmental Considerations

Accounting for the cumulative environmental impacts of Marine Energy installations is no longer deferrable since any artificial ocean structure can cause changes to the marine environment, both adverse and beneficial (Willsteed et al., 2017). The debate as to the potential impacts of offshore installations on the marine wildlife (biotic components) is still on-going, the conclusion being sometimes very controversial and not always based on scientific evidence or accurate reference environmental data (Wilding et al., 2017). The propagation of uncertainties through the predictive models used to estimate power extraction and its impact on the marine ecosystem is often overlooked, as well as the impact of device-device interactions, while field data is difficult and expensive to obtain, and current knowledge of the relevant processes involved still partial (Borthwick, 2016). It is likely that the long-term ecological side-effects of marine power plants and device farms will not be fully known until information is available from post-installation monitoring campaigns but, far from being an alibi, this consideration should prompt extra efforts and funding to preventively broaden our knowledge as to how ME devices alter the local flow hydrodynamics, with consequences on critical processes and properties, such as sediment transport, littoral drift, sea quality, biodiversity and food availability (Bonar et al., 2015; Borthwick, 2016).

In general, potentially disruptive interactions between the devices for marine energy conversion and the environment have not been ruled out. This is all the more true for the sensitive Mediterranean environment, where their installation might cause changes at a scale large enough to alter the provision of crucial ecosystem services, in particular as regards fisheries and biodiversity (Bray et al., 2016). The alteration of trophic linkages might change the distribution of fish, birds and mammals, a hypothesis that strongly demands the development of new and more appropriate metrics to be proved false before political consensus is gained around the installation of ME farms (Wilding et al., 2017). From this point of view, basin-wide analyses and theoretical considerations are insufficient, and they can only serve as a non-constraining reference for more stringent tests, accounting for the specific characteristics of prospective installation sites and technologies, on which resources should be concentrated. Metrics of change should be designed that can be unambiguously linked to ecosystem function or service provision, mainly when strongly non-linear effects are expected to be triggered. Innovative long-term monitoring techniques should also be implemented to sustain the development of predictive ecosystem models aiming to support transparent, auditable and timely decision-making (Wilding et al., 2017).

Compared to other forms of ocean energy (e.g., wave and tidal power), offshore wind energy seems to be comparatively more developed from both the technological and environmental point of view. However, Offshore Wind Farms (OWFs) have been fully operative for a relatively short period, and the research on their potential environmental impacts is therefore also limited. Moreover, current assessments of the effects of existing OWFs in Northern European Seas may not be applicable to the Mediterranean, and site-specific analyses are needed before large-scale offshore wind energy exploitation is initiated (Bray et al., 2016). The experience gained from onshore wind farms can only very carefully be extended to the case of OWFs, and for particular cases, such as the effects on bird migrations.

Environmental impacts should be assessed all along the operational life of a plant, as well as during the construction and decommissioning phases. Current assessments usually rely on three strategies:

(1) Gathering existing experience from relevant/similar activities;
(2) Implementing simulation models, and;
(3) Conducting ocean and environmental monitoring/surveys during the planning, the construction and the operational phase of the offshore plant, which is the most important (though expensive) action for an effective environmental impact assessment study. Water quality and pollution indicators should be derived and analyzed, together with the associated impacts on benthic, sea mammal, pelagic, and bird communities. Ornithological surveys may be conducted on the sea, resting and migrating birds, as well as sea mammal surveys on cetaceans and seals. The surveys should be extended onshore to assess the potential impact of on-shore stations and power transfer cables on the surrounding environment.

It is often argued that device foundations and support structures could act as artificial reefs improving biodiversity (but they might also attract invasive species) and that the interdiction of trawling within the concerned area, might be beneficial for the marine flora and fauna, but adverse effects of biofouling such as higher sedimentation rates and eutrophication have not been thoroughly investigated, nor have the consequences of the possible use antifouling chemicals. Also, the effects of prolonged exposure to noise, electromagnetic radiation, and habitat exclusion on marine animals are still to be assessed (Bray et al., 2016).

Social Acceptance

Societal acceptance is generally connected to employment prospects, esthetic concerns, stakeholder involvement, and the wellbeing of communities (Borthwick, 2016). Most of these aspects are not immediately quantifiable in terms of monetary costs or repayments, and an unbiased socioeconomic impact assessment must therefore also account for apparently intangible goods, such as the cultural and esthetic value of landscape or environmental quality. The latter not only define and interweave the multiple, intimate relations between local communities and their natural environment, but also provide vital economic advantages in the form of avoided and replacement costs, as well as of factor income, which are often only appreciated long after their disruption.

Attempting to assign monetary values to non-consumptive public goods and to their functions presents several challenges (Fausold and Lilieholm, 1996). They might even be impossible to accurately calculate, as certain intangible values lose their significance in the process. However, when evaluating the trade-offs and alternatives that are to be proposed to the public, a multidisciplinary effort must necessarily be implemented to account for the parallel economy of the commons, in the context of a mature participatory decision-making process that weighs the social and economic consequences of development and conservation (Newig, 2007; Pomeroy and Douvere, 2008; Portman, 2009). Such an approach is indeed mandatory in view of the social resistance to offshore installations that has been growing in some local communities (e.g., along the Italian Adriatic shores), and of the active role played by local representative bodies in the authorization process, which can lead to project rejection or anyway to costly delays. As a matter of fact, despite the documented widespread support of renewable energy exploitation (European Commission, 2007), on several occasions local communities oppose the installation of plants. The Not-In-My-Backyard (NIMBY) syndrome is probably responsible for this apparent contradiction between public acceptance at the local and the national level, so that individuals favor the proposed interventions only if they are implemented away from their own community (Vazquez and Iglesias, 2015). However, the multifaceted social attitudes and preferences toward complex and strategic matters such as energy production, cannot be fully accounted for by the NIMBY syndrome, and strongly depend on age, education and social rank (Kontogianni et al., 2013; Westerberg et al., 2015). Public efforts must therefore be implemented to inform and involve citizens in participatory decision-making processes, illustrating necessary trade-offs and possible alternatives (Cormier et al., 2013). In particular, inconsistencies and gaps between the proposed management measures, the risk criteria adopted and the level of risk accepted by society need to be identified, while the public must be fully aware that decisions have to be taken by the competent authority on the basis of probabilities and uncertainties (Cormier et al., 2016). Transparent communication and timely stakeholder involvement in a risk-based management approach (Stelzenmüller et al., 2018) would help find a balance between over-regulation (i.e., regulations that are too stringent with respect to the expected risk), and insufficient regulation unnecessarily exposing citizens and economic operators (GRM, 2017).

Economic Opportunities and Constraints

In the Mediterranean area, the development and implementation of offshore renewable energy technologies is expected to stimulate innovation and investment in innovation, and to reinforce the competitiveness of local and regional economic activities traditionally connected to the maritime and marine sectors or engaged in the high tech sector. Operation and maintenance costs are in fact expected to represent a considerable percentage of the future cost burden (Rademakers et al., 2009), and the intellectual property of efficient installation, operability and connection, and in general of cost-effective monitoring and management solutions will definitely represent an invaluable asset on the global market (Magagna et al., 2016). As product development comprises all the levels of the value chain, from R&D to final deployment, several competitive advantages would arise from the coordinated development of all the connected technologies, sustaining the creation of high-tech, sustainable infrastructures in cohesive investment areas and the establishment of efficient transnational business networking and collaborative R&D (European Commission, 2014).

The creation of new jobs can therefore be expected at the local, national and continental scale, adding to the already growing demand for highly qualified professionals in the EU eco-industry. As ME technologies are still at an early or intermediate stage in potentially competitive countries, the chance exists for EU countries to occupy market niches that are still to be conquered and to establish a strong market position as a technology exporter (Magagna et al., 2016).

The national perspective, however, is not sufficient to bring ocean energy technologies to the market, due to the high investment costs. Access to financial resources from international funding bodies need to be facilitated in order to help the domestic industry players achieve the "critical mass" that would speed up the industrial roll-out of products. The continuous and consistent participation of experts from Mediterranean countries in international initiatives needs to be guaranteed, and their competences and interests adequately represented in EU governing bodies (Communication From The Commission To The European Parliament, 2014; Corsatea, 2014; Magagna and Uihlein, 2015a,b; Ocean Energy Forum, 2016; European Commission, 2017c).

From the point of view of actual implementation constraints, the development of the ME sector can be hindered by conflicts with traditional maritime sectors (e.g., shipping, fishing activities, tourism) that are not always spatially compatible (European Commission, 2015). Potential conflicts clearly exist between marine energy deployment and maritime transport (e.g., increased potential risks to the safety of navigation due to higher traffic density in transit areas and shipping lanes and visual limitations), fisheries (e.g., fishing restrictions in the security zone around energy farms, gear type restrictions for the protection of submarine cables connecting energy farms to the onshore distribution grid, and potential depletion of stocks around individual sites), tourism (e.g., limited access to sea space for leisure purposes and low social acceptance) and environmental protection.

According to the available studies, however, impacts on tourism and leisure activities can be negative, positive or negligible, depending on the implementation phase of the offshore installations. In particular, temporary disruption to the tourism sector is expected during the construction and decommissioning phase of an offshore park, while during the operation phase the main threat to tourism appears to be undesirable visual intrusion, which is worst in clearer air and sunshine. Other impacts can be minimal provided mitigation measures are implemented. On examining whether potential visual nuisances can be compensated by associating reef-recreation to offshore plants or by adopting a coherent environmental policy, a study specifically devoted to installations in a Mediterranean environment indicated that age, nationality, vacation activities and loyalty to holyday destination influence the public's attitudes toward compensatory policies (Westerberg et al., 2015). No data are available for sites of particular historical interest and/or located in particularly beautiful landscapes, which are not always included in officially protected areas. It is to be noted, however, that while disamenity costs decline as the distance from the coast increases, transmission, construction, and maintenance costs typically rise with distance, therefore posing the crucial question of optimal trade-offs in the economics of near shore marine energy plants (Global Insight, 2008).

Residential property values can be negatively impacted by the presence of ME installations due to the disamenity costs of visual impacts, which might be compensated by lower property taxes. The latter, however, would result in lower property tax revenue for the country. In addition, impacts on the tourism sector would affect commercial property values (i.e., summerhouse rentals) in coastal areas (European Commission, 2007).

On the contrary, aquaculture activities are likely to profit from business ventures with the ME industry, provided these are managed on a case-by-case basis, and projects are jointly developed on the basis of adaptive management, rather than separately pursued as sectorial targets (Christie et al., 2014).

Direct positive impacts on local and large-scale economic sectors (e.g., construction, electrical and mechanical engineering, manufacturing activities, marine transport, professional services for the assembling procedures and accommodation services) are also liable to arise during the construction, the operation and the decommissioning of plants, while their operative life would lead to indirect benefits on the local district economy, thanks to the expenditures of the employees and to the continuous demand for local services, including accommodation services. Local taxes could be derived by property and excise taxes paid to the corresponding municipalities by workforce and enterprises during the construction, operation and decommissioning phases, while state taxes would include income and sales taxes paid by workforce and enterprises (Deloitte, 2012). The imposition of corporate, local and regional taxes would cause a corresponding increase of revenues through the direct, indirect and induced increase of GDP and employment.

The uncontrolled coexistence of different sectors competing for alternative uses of sea space is a primary factor of suboptimal economic development and of negative cumulative impacts on the environment. The EU Directive 2014/89/EU on Maritime Spatial Planning, by establishing a framework for the harmonization between environmental legislation, legislation on marine renewable energy, fisheries regulations and the Integrated Maritime Policy, justly aims to set the conditions for the sustainable spatial management and coherent planning of sea areas and for the cross-boundary cooperation of stakeholders and authorities.

CONCLUSIONS

The global energy system is changing, as it faces an ever-increasing demand driven by rising living standards, and the enhanced environmental awareness of civil society. In the power sector the energy mix is being redefined, and renewables largely satisfy the demand growth. Affordable, secure and sustainable energy systems are expected to progressively integrate a variety of diverse energy sources and to substantially rely on distributed generation. The EU Commission proposed a long-term vision to tackle the challenges posed by the decarbonization of the European energy system, and a package of binding policies (climate and energy package) has been implemented and reformed, to overcome distributional obstacles and enable burden sharing among member states.

In this framework, marine energy holds a great potential, although still requiring faster cost reduction. Larger demonstration projects should be facilitated in order to sustain its development from basic and applied research to its final commercial deployment, also to enable a comprehensive assessment of the impact of plants on the environment and on local and regional economies. As a matter of fact, despite the encouraging resource availability and technological development, enabling conditions for the ME sector are still to be created for the Mediterranean area, and the risk that local contingencies might limit the opportunities for development is still to be averted.

The creation of transnational clusters of specialized suppliers and research institutes would definitely contribute to the success of the Mediterranean marine energy industry, by providing tailor-made technological solutions for both the improvement of devices and adequate environmental monitoring. In the medium run, it would support technology transfer and knowledge sharing, and stimulate the development of high-tech and sustainable infrastructures in cohesive investment areas, thus concurring to generate economic growth, to enhance the security of energy supply, to foster competitiveness, and to increase the demand of high-quality professionals in new sea careers. Concerted action between Mediterranean countries would also accelerate the implementation of effective Maritime Spatial Planning strategies, and allow the harmonization of solution and regulations.

In the framework of the European Transnational Cooperation Programme, on-going projects are currently exploring innovative strategies to transform the aspirations of the marine energy sector into operational actions and agendas to be implemented in the Mediterranean region. On the other hand, the Horizon 2020 Research and Innovation Programme provides specific funding for the development of research and roadmaps at the continental level, that can help reach the targets agreed in the EC Declaration of Intent (European Commission, 2017a). Both the on-going and foreseen actions are expected to enhance coordination between Member States and the EC and to sustain the development of a structured path to the gradual implementation and commercial viability of marine energy technologies. The widest possible range of connected stakeholders is expected to be involved in the process, through knowledge and information sharing initiatives, also with the aim of filling the existing gap between Northern and Southern Europe. Technological solutions suitable for the Mediterranean environment could then be exported to North African and Middle East countries, as part of the EU declared intent to cooperate with third countries to meet their EU 2020 targets (Renewable Energy Directive 2009/28/EC).

Constant monitoring and updated mapping of the different activities that are currently being undertaken across Europe is recommended, in order to avoid duplication and realize the full synergy potential of different actors, either sharing high product or market affinities or facing common governance and administrative issues. The optimization of the use of funds for the marine energy sector is also a priority, and financial solutions tailored to the Mediterranean sub-national, national and regional contexts should be envisaged and scaled up as appropriate. Mobilization of investments, both public and private, is imperative to achieve scale and scope. An overall policy framework is therefore needed, that is capable of supporting investment-led development in the area, while balancing the need for attractive risk-return rates with the need for affordable and sustainable energy production. To this end, agreed technical, environmental and financial metrics need to be designed in order to allow the objective comparison of different technologies, and transparency and accountability needs to be guaranteed all along the implementation, operation and decommissioning of plants in the real environment.

The forthcoming years will be crucial in unlocking the potential of marine energy in the Mediterranean, through the cumulative impact of targeted research, continuous support to industrial development and deployment, and the streamlining of administrative procedures and funding instruments.

AUTHOR CONTRIBUTIONS

GP and GS conceived the work. GP wrote the manuscript with support from GS, AC, MS, and AC made the Figures. All authors designed the review and contributed to the final manuscript.

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